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EVALUATION OF THERMAL PROTECTION OF FABRICS AND UNIFORM SYSTEMS FROM SIMULATED NUCLEAR PULSE IRRADIATION

By

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13. ABSTRACT (Maximum 200 words)

Fabric materials were tested under simulated nuclear thermal pulses from the solar furnace located at Odeillo, France. Various nuclear yields were used in the testing and a statistical analysis was done to compare the performance of the materials against the different yields and for different pulse shapes. The fabric performance was compared for each of the test conditions, and no significant difference was noted among the various fabrics when irradiated by different yields and pulse shapes.

Uniform ensembles, French and American, were evaluated for thermal protection when irradiated by a Thermal Radiation Simulator (TRS) located at Gramat, France. They were tested with fluence levels of approximately 40 and 60 J/cm^2. Video and photographic coverage were used to assess physical damage and the output of an instrumented manikin was used to calculate skin damage. Skin damage is recorded as second degree or greater burns.

Pulse shapes and yields from simulated nuclear blasts were varied when testing uniform systems. No significant difference was noted in temperature rise due to either pulse shape or nuclear yield.

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PREFACE

The study presented in this report was a collaborative effort in thermal transfer of materials and uniform systems between the laboratories in France, Solar Furnace at Odeillo and Centre d'Etudes de Gramat, and the U.S. Army Soldier System Command, Natick RD&E Center, Natick MA under the auspices of MWDDEA-A-80-FR-1265, Nuclear Weapons Effects. The solar furnace was used to study the effects of a simulated nuclear thermal pulse on fabric materials and sensor response.The Thermal Radiation Simulator (TRS) at Gramat was used to study the response of uniform systems to a simulated nuclear thermal and blast wave synergistic effect. The Solar Furnace and the TRS/blast facilities were provided by France and the detecting/recording system in the forms of skin simulants and instrumented manikin were supplied by the U.S. Each country supplied uniforms and materials for testing. Video and photographic coverage and the required logistics were provided by the French laboratories.

This study was supported in part by the program Thermal Response of Uniforms to Nuclear Thermal Threat, Project AH98CA, Work Unit B00, during the period from 14-27 November 1993.

EVALUATION OF THERMAL PROTECTION OF FABRICS AND UNIFORM SYSTEMS FROM SIMULATED NUCLEAR PULSE IRRADIATION

1. INTRODUCTION

A cooperative test program with French laboratories under the auspices of DEA-1265 was initiated to determine the response of materials and uniforms to simulated nuclear pulses having various energy outputs (yields). Both fabrics and uniform systems are included in the test program. American army fabrics were tested for thermal transfer properties and skin protective characteristics using the solar furnace facility at Odeillo FR. Uniform systems were tested at the Thermal Radiation Simulator (TRS) at Gramat FR. Thermal transfer measurements were made using calorimeters and skin simulants from which skin damage criteria were calculated. A separate study on the response of the simulants to short pulses was conducted to verify their accuracy in thermal measurements.

Absorbance measurements were made on the different colors in the camouflage pattern of the cloth materials using a solar spectrophotometer developed by the French. The assessment of thermal damage caused by the different colors in each fabric was registered by visually noting the physical changes in the burn patterns associated with the radiation pulse. The degree and characterization of the coloration significantly affects the property of thermal transfer and burning.

2. SOLAR FURNACE STUDIES

The solar furnace was used to generate thermal pulses that were representative of 30 kt, 100 kt and 300 kt yields with fluence levels of 5,7, and 10 cal/cm^2. Seven (7) different cloth materials were tested against these pulses engendering a total of 84 individual irradiances. Measurements involved recording the temperature rise on the back surface of the sample using calorimetry and a time-temperature profile using the skin simulant detector.

A study on the response of skin simulants to short (<0.5 s) thermal bursts was conducted to measure their accuracy at time frames characteristic of low energy yields. Both simulated nuclear pulses and trapezoidal pulses were used in this study.

2.1 Fabrics

Table 1 describes the materials that were tested using the solar furnace at Odeillo, France. The series descriptor (A thru G) is used throughout this report to identify these materials.

TABLE 1

MATERIAL DESCRIPTION

Series	Description
A.	100% cotton ripstop, woodland camouflage print
B.	50/50 polyester/cotton ripstop poplin, woodland camouflage print
C.	50/50 nylon/cotton ripstop poplin, woodland camouflage print
D.	100% cotton ripstop poplin, 6-color desert camouflage print
E.	50/50 polyester/cotton ripstop poplin, 6-color desert camouflage print
F.	50/50 nylon/cotton ripstop poplin, 6-color desert camouflage print
G.	50/50 nylon/cotton twill, 6-color desert camouflage print
H.	50/50 nylon/cotton twill, 3-color desert camouflage print

The reflectance of each color of the camouflage pattern was measured using the sun (solar spectrum) as the light source and a photometer to detect and hence measure the reflected energy. Table 2 lists reflectance values for the colors comprising the four-color and six-color pattern camouflage patterns.

TABLE 2

REFLECTANCE VALUES

4 Color Pattern		6 Color Pattern	
Color	% Reflectance	Color	% Reflectance
Black	10	Black	10
Brown	33	Dark Brown	25
Green	36	Medium Brown	27
Tan	43	Light Green	39
		Medium Tan	43
		Light Tan	52

Fabric samples were irradiated using simulated nuclear pulse profiles having energy densities of 5, 7 and 10 cal/cm^2 for 30 kt, 100 kt and 300 kt yields. Testing at 10 cal/cm^2 was too severe in that the materials flamed and were totally consumed before they could be extinguished. Consequently a fluence level of 7 cal/cm^2 was substituted for the 10 cal/cm^2 and subsequent testing continued at 7 and 5 cal/cm^2 only.

The power (energy per second) contained in a nuclear pulse is a function of yield. The relationship between fluence and flux for a particular nuclear yield is shown below in Table 3. The differences in the power levels (flux) for each yield are due to the change in the shape of the nuclear pulse. The larger the yield, the longer the pulse length and the longer it takes to reach the maximum power level after the start of the pulse. Since the pulse shape changes for comparable fluences and different yields, the integration of the curves gives different flux values.

TABLE 3

FLUENCE/FLUX YIELD EQUIVALENTS

YIELD	FLUENCE	FLUX
30 kt	10 Cal/cm^2	86 Watts/cm^2
	7 " "	60 " "
	5 " "	43 " "
100 kt	10 Cal/cm^2	50 " "
	7 " "	35 " "
	5 " "	25 " "
300 kt	10 Cal/cm^2	32 " "
	7 " "	22 " "
	5 " "	16 " "

The materials were tested at the described fluence levels for the corresponding yields using the solar furnace as the source and a calorimeter behind the sample as the detector. The resulting indicator of thermal transfer was temperature rise at the back surface of the fabric which is converted to transmitted fluence from which skin damage can be calculated. Table 4 presents the data obtained for the described fabric series A through G.

TABLE 4

MATERIALS EXPERIMENTAL DATA

Fabric Series	Yield/ Fluence	Color	Observed	Max Temp Face (C)	Incid Fluen J/cm^2	Trans Fluen J/cm^2	Incid/ Trans (%)
A							
A1A	30kt86W	Dk Brown	Burned	415	33.6	34.4	102
A1B	30kt43W	Lt Green	Lt Smoke	211	16.8	14.2	85
A2A	100kt25W	Black	Lt Smoke	208	16.6	17.6	106
A2B	100kt50W	Dk Green	Lt Smoke	293	33.1	24.0	73
A4A	300kt16W	Dk Brown	Lt Smoke	186	17.1	15.7	92
A4B	300kt32W	Lt Green	Lt Smoke	274	32.2	25.8	80
B							
B1A	30kt86W	Dk Brown	Flamed	401	33.6	34.2	102
B1B	30kt43W	Dk Green	Lt Smoke	199	16.8	12.6	75
B8A	100kt25W	Lt Green	Lt Smoke	188	16.6	13.5	81
B8B	300kt16W	Black	Lt Smoke	240	17.1	18.1	106
B2A	30kt60W	Black	Smoke	334	23.4	20.9	89
B2B	100kt35W	Dk Green	Smoke	234	23.2	14.5	63
B3A	100kt35W	Dk Green	Sm/char	nm	23.2	18.0	78
B3B	300kt22W	Dk Brown	Sm/char	237	23.6	19.5	83
C							
C5A	30kt43W	Dk Green	Lt Smoke	164	16.8	13.9	83
C5B	100kt25W	Lt Brown	Lt Smoke	150	16.6	12.6	76
C7B	300kt16W	Dk Brown	Lt Smoke	151	17.1	15.9	93
C11A	30kt60W	Lt Brown	Lt Smoke	196	23.4	17.6	75
C11B	100kt35W	Dk Green	Sm/char	197	23.2	19.1	82
C7A	300kt22W	Black	Smoke	241	23.6	23.2	98
D							
D4B	30kt43W	Lt Green	*	171	16.8	12.4	74
D4A	100kt25W	Md Brown	*	178	16.6	15.3	92
D7A	300kt16W	Tan	*	133	17.1	12.5	73
D7B	30kt60W	Dk Brown	*	254	23.4	19.8	85
D6A	100kt35W	Lt Green	*	183	23.2	16.9	73
D6B	300kt22W	Tan	*	156	23.6	17.0	72
E							
E15A	30kt43W	Tan	*	158	16.8	13.2	79
E15B	100kt25W	Md brown	*	167	16.6	15.8	95
E3A	300kt16W	Md Brown	*	174	17.1	14.8	87
E6A	30kt60W	Lt Green	*	191	23.4	15.1	65
E3B	100kt35W	Lt Green	*	190	23.2	17.6	76
E6B	300kt22W	Tan	*	161	23.6	15.3	65

* not observed

TABLE 4 (Cont'd)

Fabric Series	Yield/ Fluence	Color	Observed	Max Temp Face (C)	Incid Fluen J/cm^2	Trans Fluen J/cm^2	Incid/ Trans (%)
F							
F9A	30kt43W	Tan	*	131	16.8	12.3	73
F9B	100kt25W	Md Brown	*	149	16.6	15.0	90
F2A	300kt16W	Md Brown	*	164	17.1	14.9	87
F2B	30kt60W	Lt Green	Lt char	328	23.4	17.1	73
F10A	100kt35W	Lt Green	*	169	23.2	19.1	82
F10B	300kt22W	Lt Green	*	160	23.6	18.7	79
G							
G9A	30kt43W	Tan	*	132	16.8	12.4	74
G9B	100kt25W	Dk Brown	*	146	16.6	15.2	92
G4A	300kt16W	Md Brown	*	148	17.1	15.5	91
G4B	30kt60W	Lt Green	*	193	23.4	16.6	71
G5A	100kt35W	Lt Green	*	158	23.2	17.3	75
G5B	300kt22W	Tan	*	147	23.6	15.5	66

* not observed

The headings in table 4 are defined as follows:

Yield/Fluence..simulated nuclear pulse shape and energy
Observed.. Observation of the fabric/pulse interaction. Smoke and charring.
Max Temp Face..Maximum temperature recorded at the surface of the fabric in degrees Celsius.
Incid Fluen..Fluence incident on the sample in joules/cm2.
Trans Fluen..Fluence transmitted through the sample
Incid/Trans..Ratio of incident fluence to transmitted.

The H series was not included in the tests since the three colors it contains are also present in the G series and time did not allow for redundant testing.

2.2 STATISTICAL ANALYSIS

The ratio of the energy transmitted through a fabric sample to the energy incident on the sample (expressed as a percentage of the incident energy) was chosen as the measure of nuclear thermal flash protection provided by the material. The data were grouped into two fluence ranges, 17 J/cm^2 and 23 J/cm^2. Data for a given fluence were grouped for each fabric regardless of the color of the portion of the sample irradiated. A multifactor analysis of

variance (ANOVA) and Duncan's multiple range test were performed at each fluence level to determine any significant differences in attenuation between the fabric samples or as a result of the weapon yield.

Analysis of variance:

At 17 J/cm^2 incident fluence the following analysis, shown in Table 5 was determined for the fabric materials.

TABLE 5

ANALYSIS OF VARIANCE FOR FABRICS IRRADIATED AT 17 J/CM^2

Fabric:	D	F	C	G	E	B	A
Mean:	79.7	83.3	84.0	85.7	87.0	87.3	94.3

Yield:	30 kt	100 kt	300 kt
Mean :	77.6	85.6	89.9

Source	**degrees of freedom**	**mean square**	**standard error**
Between fabrics	6	20.89	3.56
Between yields	2	272.2	6.63
Error	12	87.8	

For fabrics:	p:	2	3	4	5	6	7
	Rp:	15.38	16.20	16.66	16.95	17.23	17.52
For yield:	p:	2	3				
	Rp:	28.64	30.17				

The standard errors multiplied by the significant Studentized ranges (at a 99% level) for n=12, yield the shortest significant range, Rp, by which the differences between the means are judged. To declare two means to be significantly different, they must differ by a value at least as large as the Rp calculated for the sample range they span. For example, fabrics D and C span three sample means when the means are ranked in ascending order as above. Therefore they must differ by at least 16.66 to be declared significantly different; they do not. To facilitate the determinations, those means which are <u>not</u> considered different from each other are underlined.

At 23 J/cm^2 incident energy a similar analysis was made and the results are shown in Table 6.

TABLE 6

ANALYSIS OF VARIANCE FOR FABRICS IRRADIATED AT 23 J/CM^2

Fabric:	E	G	D	F	B	C
Mean:	68.7	70.7	76.7	78.0	80.8	85.0

Yield:	30kt	100kt	300kt
Mean:	76.3	76.4	77.2

Source	degrees of freedom	mean square	standard error
Between fabrics	5	113.10	3.82
Between yields	2	1.25	6.04
Error	10	73.00	

For fabrics:	p:	2	3	4	5	6
	Rp:	17.11	18.07	18.64	18.95	19.33

For yield:	p:	2	3
	Rp:	27.06	28.57

The preceding analysis indicates that no significant difference in attenuation of the thermal pulse was seen between any of the fabrics at either fluence level (at the 99% confidence level). Also, the difference in the pulse characteristics simulating the three yields had no significant effect on the attenuation provided by the fabrics.

2.3 Simulants

Skin simulants were irradiated with short pulses (trapezoidal pulses) and temperature-time response profiles compared to calorimeter data in calculating skin burns. The simulants were developed at Natick for use in the instrumented manikin to calculate skin burns associated with nuclear explosions. Previous work done at the solar furnace have raised questions about the accuracy of simulants in their response to short pulses when compared to calorimeter calculations. To investigate the possible discrepancy in response, we tested the simulants with a short pulse and compared the resulting time-temperature profile to that of a nuclear pulse having the same energy content. Similar type pulse shapes are used in the Thermal Radiation Simulator (TRS) which has been and is currently being used in system evaluations.

2.3.1 Pulse Characterization

A trapezoidal pulse was generated by the solar furnace and used

to irradiate skin simulants. The four shortest pulses available at the solar furnace and their profiles are shown below. The flux (power density) is a measure of the power contained within the pulse envelope. Nuclear shaped pulses with similar flux properties of two of the short pulses (sens2 and sens3) are profiled as well and were used for comparison studies.

Trapezoidal Pulse

ID	Rise Time	Dwell Time	Fall Time	Flux
Sens1	0.1 s	0.9 s	0.1 s	5 W/cm^2
Sens2	0.1	0.4	0.1	10
Sens3	0.1	0.2	0.1	17
Sens4	0.1	0.1	0.1	25

Nuclear Pulse

ID	Yield	Flux
Sens5	15 kt	14 W/cm^2
Sens6	30 kt	10 W/cm^2

For each of these pulses the energy content was held constant at 5 joules.

2.3.2 Results

The two simulants (sens2 and sens3) were used to measure temperature vs time profiles and the time-temperature results compared with nuclear pulses having the same power density (W/cm^2). The comparisons were made for a 30 kt nuclear yield

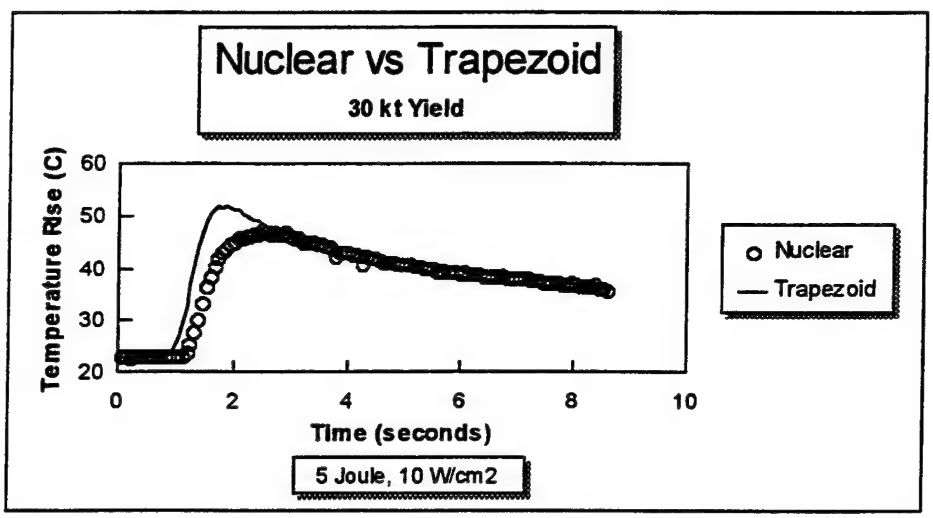

Figure 1. Nuclear vs Trapezoid for 30 kt Yield

($10\ W/cm^2$) vs a trapezoidal pulse at $10\ W/cm^2$ and a 15 kt yield ($14\ W/cm^2$) vs a trapezoidal pulse ($17\ W/cm^2$).

For the 30 kt nuclear pulse ($10\ W/cm^2$), Fig. 1, a maximum temperature rise of 47°C was reached at 2.49 s, and for the trapezoidal pulse the maximum temperature was 52°C at 2.07 s.

For the 15 kt nuclear pulse ($14\ W/cm^2$) curves, Fig. 2, the maximum temperature attained was the same for both the nuclear and trapezoidal pulses. The nuclear pulse reached its maximum value at 2.00 s and the trapezoidal pulse at 1.52 s. These results are not unexpected since the rise time for the trapezoidal pulse is faster than the nuclear. With higher yields, the maximum temperature reached is a function of energy and pulse shape. To ascertain the true significance of the differences observed, a more comprehensive study should be effected. An effort of this

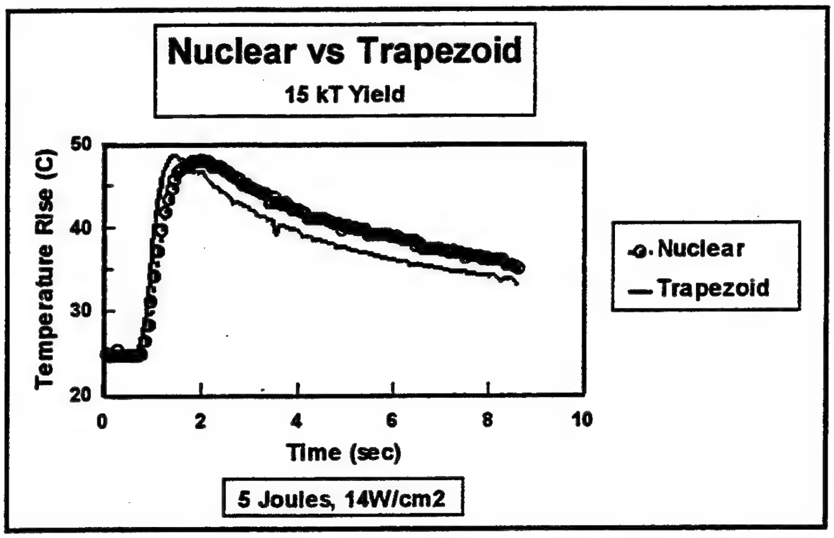

Figure 2. Nuclear vs Trapezoid for 15 kt Yield

magnitude is beyond the scope of this study at present. In general, for the response times considered relevant to this test series, the simulants respond reasonably well and do not significantly differ from indicating a true time-temperature relationship.

3. THERMAL RADIATION SIMULATOR (TRS) STUDIES

3.1 Experimental Methods

American and French uniform systems were tested with pulses produced by the thermal radiation simulator (TRS) system located at Gramat FR. The TRS simulates the overall flux associated with nuclear explosions although it lacks the proper pulse shape and spectral distribution of a nuclear pulse. It has a spectral

distribution of a 2800K black body and a trapezoidal pulse shape. It has been used in the past for large-scale system testing including uniforms and system ensembles.

The data acquisition and analysis system (instrumented manikin, hardware and software, and skin simulants) were designed and built by Natick and used in all the experimental measurements for both the U.S and French materials and uniforms.

3.2 Uniforms

The following is a description of the test uniform systems.

U.S. Uniforms:	BDU 50/50 Nylon/Cotton consisting of a jacket and pants	
	CB Garment consisting of boots, gloves a jacket and pants.The outer material was composed of Nomex(R) with 5% Kevlar(R)	
French Uniforms:	TOM(1):	Polyester/Cotton Uniform consisting of a jacket, pants, boots and a hood.
	TOM(2):	Identical to TOM(1)
	T3P:	Flame Retardant Carmel/Viscose Uniform in a one piece configuration with hood
	S3P:	CB Suit consisting of a jacket and pants, hood and black leather boots

3.3 Data Acquisition/Display

A complete description of the instrumented manikin and its functions can be found in reference 1. The manikin data are acquired from 124 skin simulants consisting of thermistors situated throughout the manikin body. Data collection and recording begin one second prior to irradiation and continue for eight seconds after cessation, or for any determined time interval. Thermistor voltages are read 20 times per second and recorded on floppy disks for processing. The thermistor voltages are converted to temperature values and numerically integrated with respect to time. These data are used to calculate skin damage. Second degree and higher burn calculations are subsequently recorded and plotted out as damage areas on the manikin profile. The manikin plots are graphical representations of the human body and outline the area, approximately 17 square inches, used in the calculation of skin burns. The area described by second degree and higher skin burns is used to determine thermal protection as a percentage of damage versus the total body area.

The printout displays in the following figures (3 through 8) display second degree and higher skin burn damage sustained by

each body area. The areas filled in by a black color depict second degree or greater skin burns. The head and feet areas are not instrumented and consequently cannot respond to temperature changes and thus will remain uncolored (filled-in). In those instances where gloves are not part of the uniform ensemble, the hands will appear black denoting a skin burn. Any part of the manikin that is not protected will experience the same phenomenon.

The character of the test set-up and of the apparatus, the TRS, allows only the front of the manikin to receive thermal radiation. The back of the uniforms under test are protected by the manikin itself and would therefore experience no damage. However, in cases where the flames wrap around from the front, skin damage is noted. This is apparent in some of the back views of the manikin printouts as shown in figures 3, 6, 7 and 8.

A complete description of the test results containing comprehensive visual aids has been published by researchers at the Centre d'Etudes de Gramat. See reference 2.

3.4 Results

Figures 3 through 8 are the manikin printouts showing the skin burn distribution indicative of each uniform system tested. The comments describing the physical evidence of damage and the flaming and smoking were observed and recorded. Flaming and smoking times were obtained from recorded video tapes in real time and subsequent to the event. Timing marks recorded on each video frame provided the information on flaming and smoking. Visual examination of the uniforms after irradiation furnished the necessary information to describe the physical damage.

Table 7 summarizes the data obtained during the TRS testing. Included are the observations in real time via video cameras and recordings and visual observations of the resulting damage after irradiation.

TABLE 7

SUMMARY OF TRS TEST RESULTS ON UNIFORM SYSTEMS

Test #	Material Tested	Flux (W/cm^2)	Fluence (J/cm^2)	Results
1	TOM1 (France)	56	64	Inflammation Total destruction
2	TOM2 (France)	36	40	No Flaming Shrinkage
3	T3P (France)	38	40	Carbonization of the fabric with localized destruction
4	CB Garment (USA)	58	61	Shrinking of the fabric and color change. Some carbonization
5	BDU 50/50 Nylon Cotton (USA)	35	38	Black areas were carbonized.Negligible damage
6	S3P (France)	38	40	Inflammation Total destruction

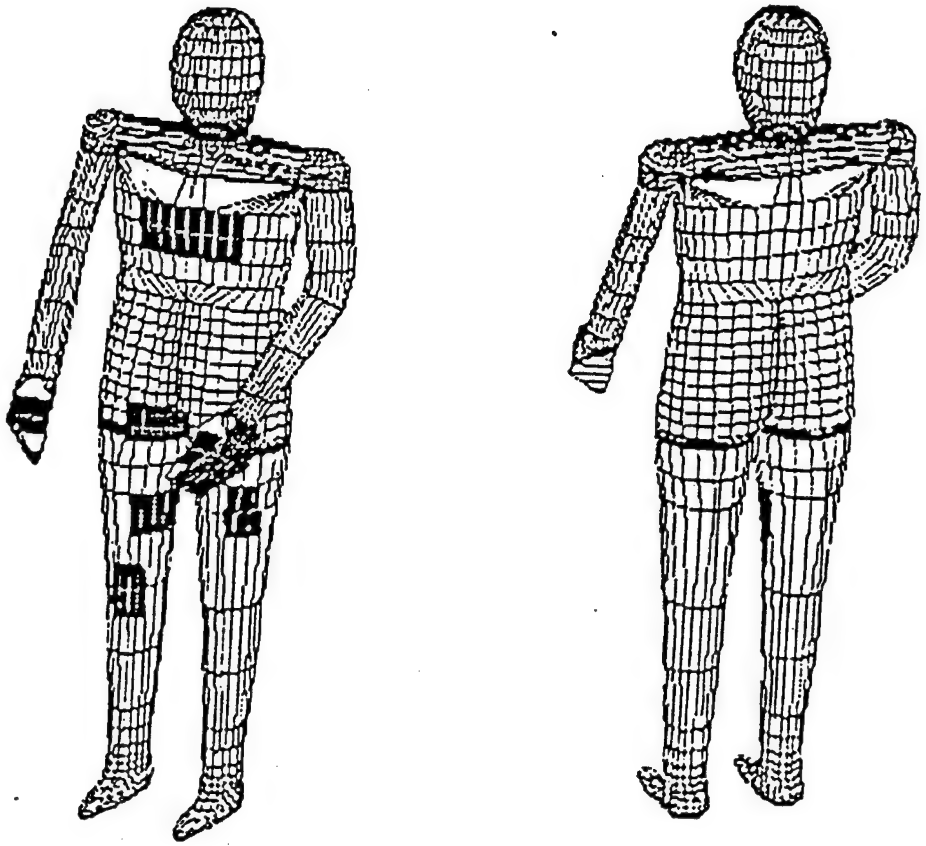

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Figure 3. Manikin display for test 1, TOM1

Test TOM1: Flux = 56 W/cm^2 Fluence = 64 J/cm^2

At 0.5 seconds, smoke from the black parts of the system and at 0.9 seconds from the pants. After 2 seconds, small flames appeared and at 5 seconds, the total uniform was engulfed in flames. At 35 seconds, the total uniform was completely destroyed.

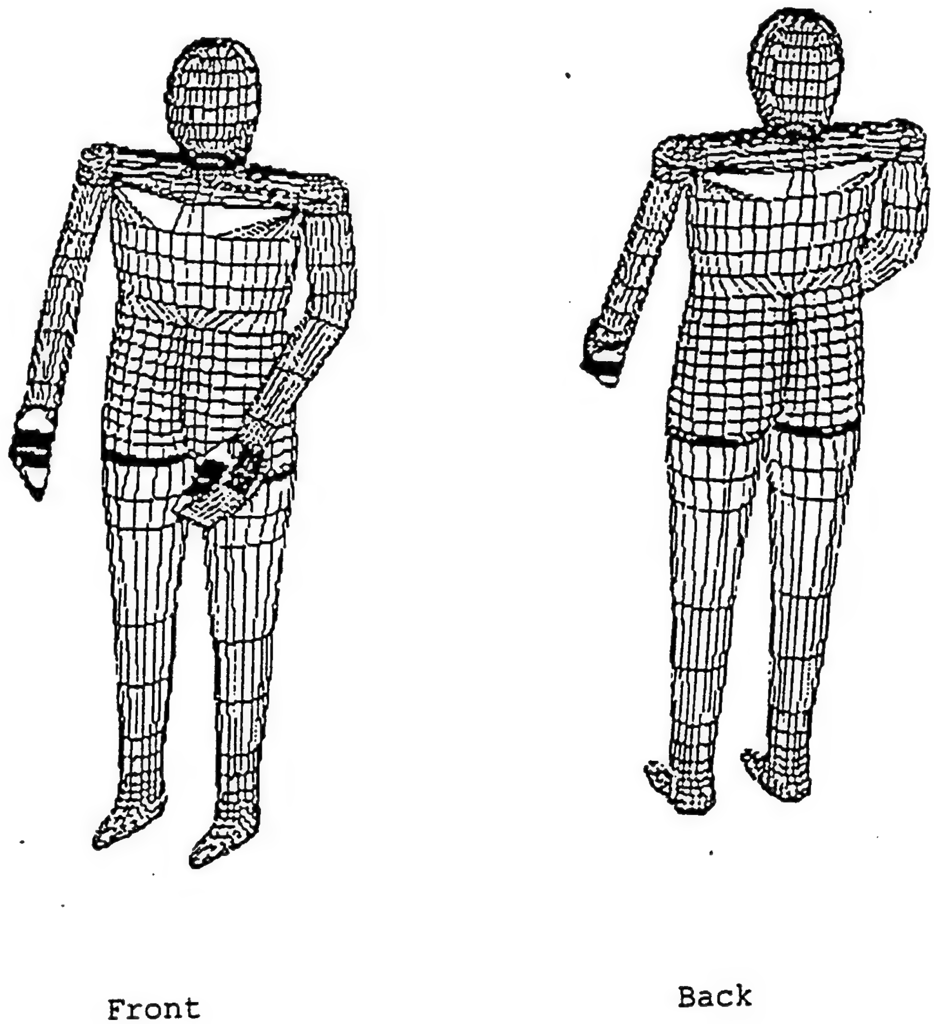

Figure 4. Manikin display for test 2, TOM2

Test TOM2: Flux = 36 W/cm^2 Fluence = 40 J/cm^2

At 0.6 seconds, smoke began to appear from the black parts of the system. After about 2 seconds, smoking began to abate and cleared completely after 3 seconds. No flaming was observed.

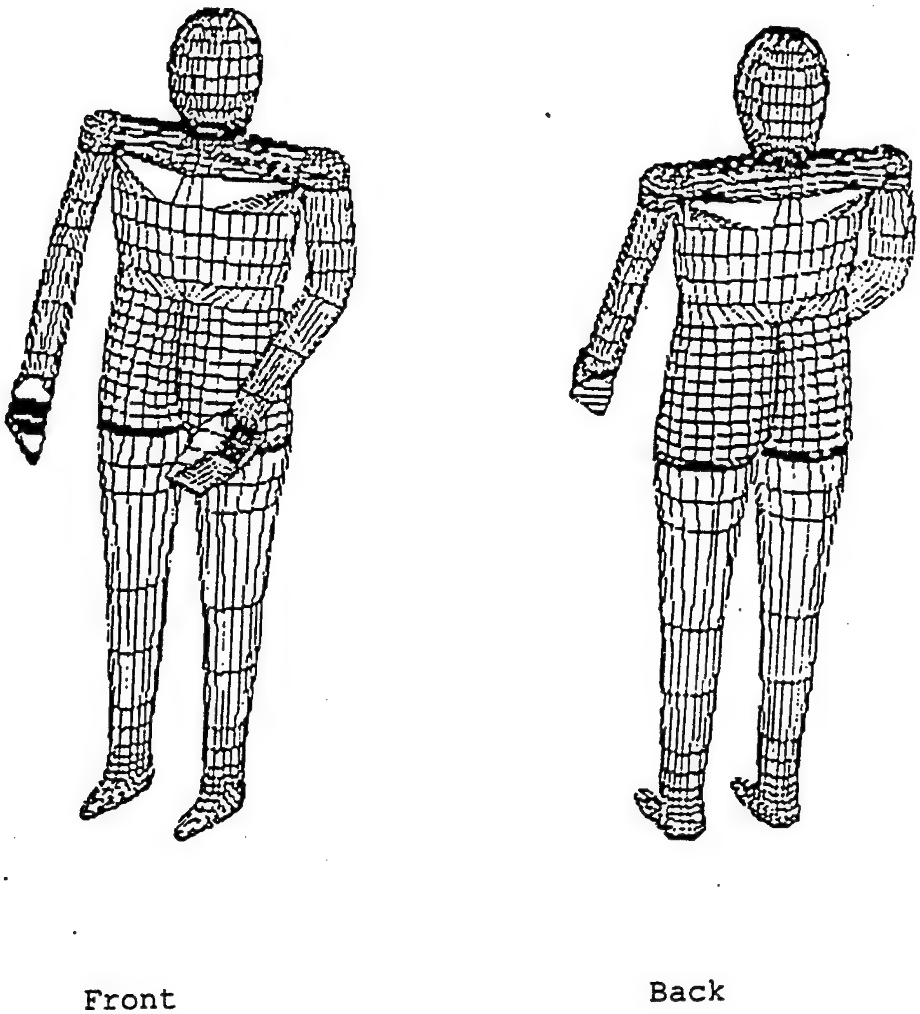

Figure 5. Manikin display for test 3, T3P

Test T3P: Flux = 38 W/cm^2 Fluence = 40 J/cm^2

Appearance of smoke from the face of the manikin began to be evident at 0.5 seconds. At 1.0 second the smoke became thick and intense. At 1.6 seconds, flaming of the outer shell commenced. The flames self-extinguished at about 2.0 seconds. After 8.0 seconds, all smoking ceased.

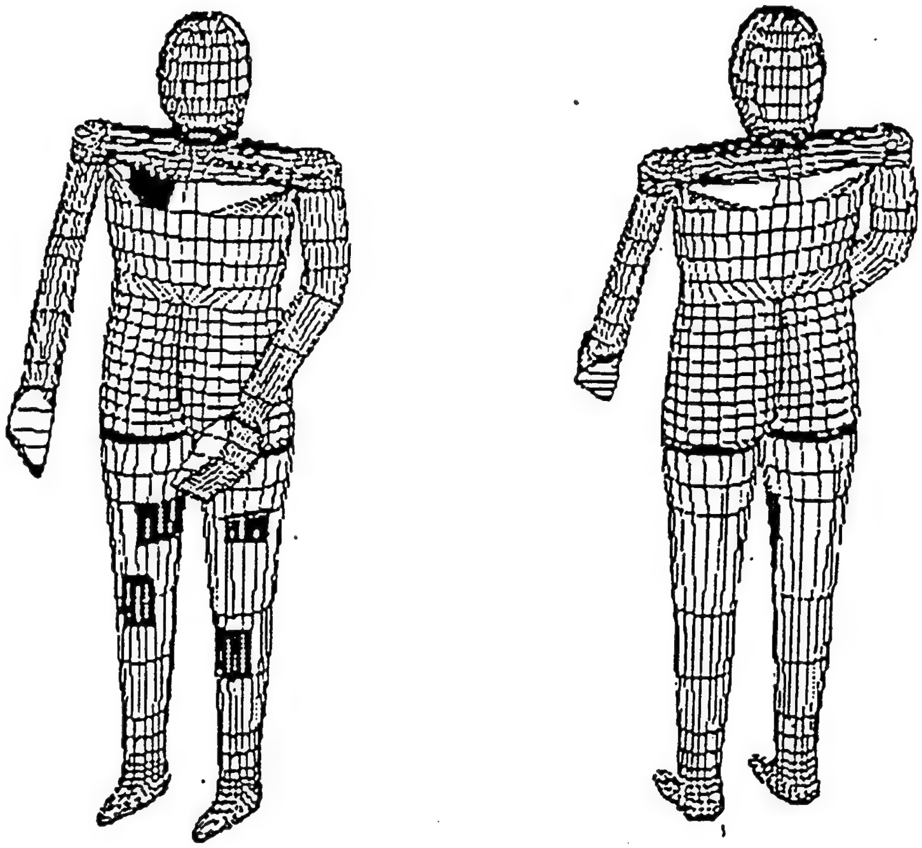

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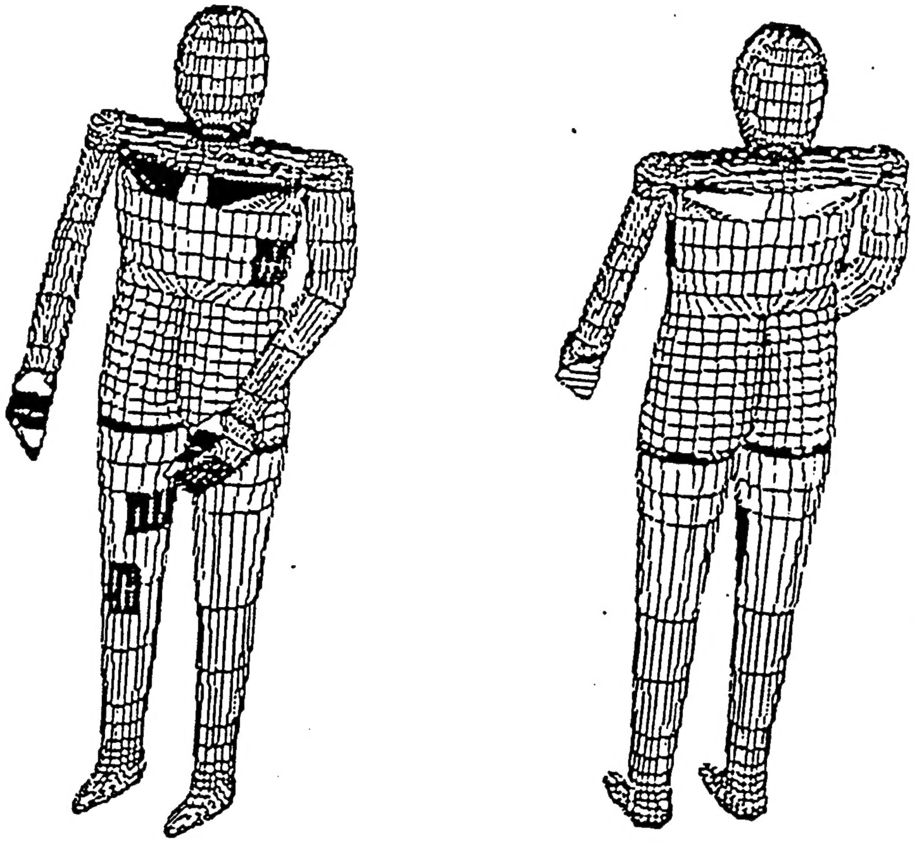
Figure 6. Manikin display of test 4, CB Garment

Test CB Garment: Flux = 58 W/cm² Fluence = 61 J/cm²

At approximately 0.4 second, smoke began to appear from the gloves. After 0.9 second, smoke was apparent from all parts of the ensemble. Flaming began at 1.5 seconds in the lower extremities becoming extensive after 2 seconds. Flaming ceased after 2.7 seconds with some flaming continuing on the velcro fasteners. After 35 seconds all flame and smoke ceased.



Front Back

Figure 7. Manikin display for test 5, BDU 50/50 NYCO

Test BDU 50/50 Nylon Cotton: Flux = 35 W/cm^2 Fluence = 38 J/cm^2

After 1.0 second from initial irradiation smoke began to emanate from the hands and feet of the manikin. There were neither boots or gloves on the manikin so the smoke was from residue on the manikin surface. After 1.5 seconds, there was a slight movement of the jacket. Very small amounts of smoke were evident from the test.

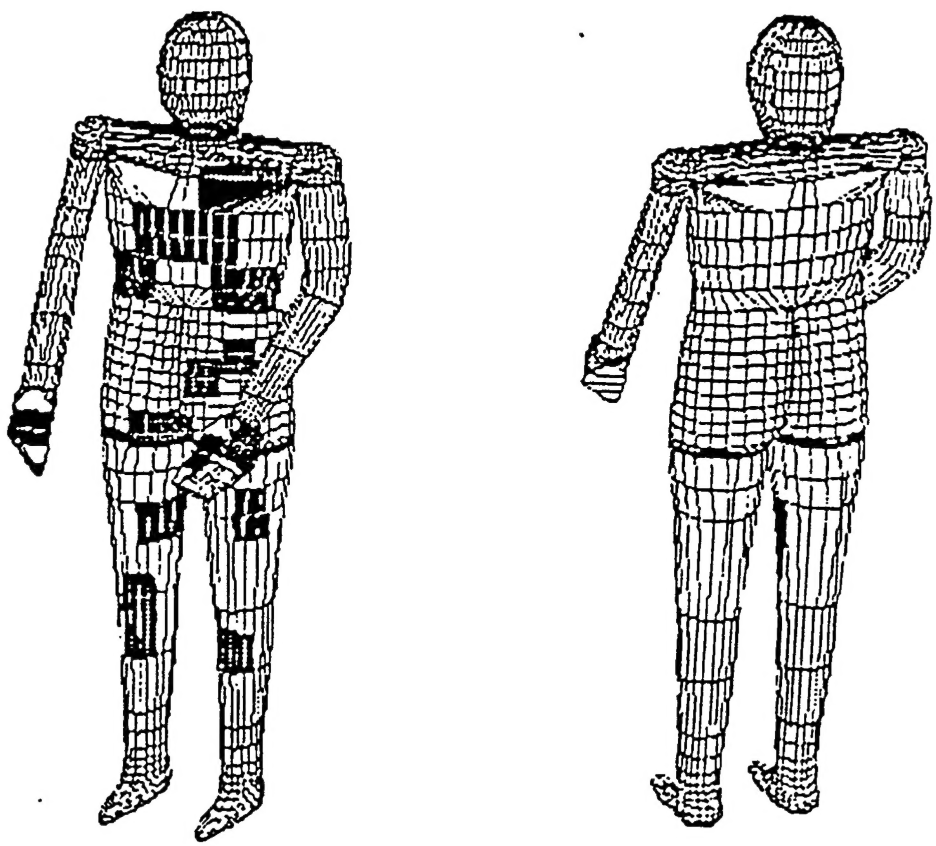


Figure 8. Manikin display for test 6, S3P

Test S3P: Flux = 38 W/cm^2 Fluence = 40 J/cm^2

After 0.8 second, there was smoke generated. At 2.0 seconds, flaming began and after 5.0 seconds, the total ensemble was engulfed in flames.

The instrumented manikin test is the final thermal evaluation for a uniform. Generally, data obtained in the laboratory is useful only for comparing different materials. In a uniform system, the response to a thermal pulse incorporates all aspects of use including extra protection because of double layers i.e. pockets, air pockets due to the drape of the material, etc. The areas receiving severe burns are shown in the printout displays as black areas. This darkness would point out the areas where more protection is needed. Where flaming occurred, the time to reach severe burn damage can be calculated from the time-temperature data recorded for each simulant. In general, the instrumented manikin test is necessary to assess fully the protective properties of a uniform system.

4. CONCLUSIONS/RECOMMENDATIONS

The data derived from the study of the various fabrics and the subsequent statistical analysis indicate no significant differences in the attenuation of the thermal pulse among the fabrics at either fluence level, 17 J/cm^2 or 23 J/cm^2 (at the 99% confidence level). The study also showed there was no significant effect on the thermal attenuation through each fabric as a result of the differences in the pulse characteristics for the three yields used, 30 kt, 100 kt and 300 kt.

Comparisons were made for the test configuration consisting of a 30 kt nuclear yield (10 W/cm^2) vs a trapezoidal pulse at 10 W/cm^2 and a 15 kt yield (14 W/cm^2) vs a trapezoidal pulse (17 W/cm^2). The maximum temperatures attained were approximately equal but reached these values quicker for the trapezoidal pulse than for the nuclear. These results are to be expected since the rise time for the trapezoidal pulse is much faster than the nuclear. A more comprehensive study should follow on this testing in order to determine accurately the true significance of the differences observed. In general, for the response times considered relevant to this test series, the simulants respond reasonably well and can be used to obtain a reliable time-temperature relationship.

The instrumented manikin tests provide data that are useful in assessing protective properties of a complete uniform system. The damage assessment in terms of skin burns is presented in graphic form, indicating the areas of weakness in thermal protection. These graphics will provide designers information for future efforts to address the weaknesses. Since laboratory data are insufficient to totally assess protection, the data from instrumented manikin tests that incorporate all aspects of physical positioning, such as double layers, i.e., pockets, air pockets due to the drape of the material, etc., become the true measure of accurately detailing thermal protection.

5. REFERENCES

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2 D. Mergnat and R. Delbois, Experimentation de Tenues du Combatant, Centre d'Etudes de Gramat, DGA Report E-94-02, 1994. This document is available from the Director of Research Studies and Techniques (DRET). This contains priority information and has limited distribution.